

Minimizing reverse current flow due to distributed generation via optimal network reconfiguration

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Received: 16.03.2016

Accepted/Published Online: 23.12.2016

Final Version: 30.07.2017

Abstract: Distributed generation (DG) is widely used to minimize total power losses in distribution networks. However, one of the problems of DG in a grid system is reverse current flow (RCF), which is when the DG output becomes greater than the connected load. Therefore, this paper proposes a multiobjective artificial bee colony (MOABC) algorithm to determine the optimal network reconfiguration for reducing total RCF in DG. The proposed algorithm is tested on 33-bus radial distribution systems in two different scenarios, i.e. base case and with 50% load. The proposed technique can reduce reverse current by up to 93%; however, the total power loss in the system will increase by 7%. Therefore, a suitable weight value is needed in MOABC for balancing the effect of RCF and the power loss value.

Key words: Distributed generation, reverse current flow, artificial bee colony, multiobjective optimization

1. Introduction

With the advent of restructuring in power systems, different steps are being taken to improve their overall efficiency and reliability, including placement of distributed generation (DG) units nearer to the load demand. DG normally includes solar, wind, biomass, combined heat and power, or small rating power plant. The main advantages of DG include low investment cost, managing transmission line congestion [1,2], reduction in greenhouse gas emission [3], minimization of power losses [4,5], possible islanding operation that minimizes interruption time, and increased reliability [6–8]. Thus, many researchers are focusing on optimizing DG size or placement in distribution networks, with different objective functions to improve its performance.

DG placement changes the nature of the power system from a passive to an active network. Different issues are being observed due to this changing nature of the system, including changing fault level, reduced reach of impedance, and islanding operations [9–12]. Reverse current flow (RCF) in different branches of the network is also a major issue due to DG placement. RCF affects the loading of the network. For example, when DG penetrations exceed the minimum in the front feeder load, the net power flow of the feeder will be reversed (i.e. towards the main substation), particularly during the light load [13]. Such RCF may affect the settings of existing fuses and other protection devices. Although changing the existing protection devices to ones with high protection ratings may solve the RCF problem, this solution is not feasible due to the high initial

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cost. Therefore, in this paper, a new strategy based on network reconfiguration has been proposed to reduce the amount of RCF due to DG placement. In the literature [14–16], network reconfiguration has been used to minimize total active power losses in networks. However, by varying the position of the tie and sectionalizing switches, the topological structures of the distribution system and the power flow in the network changes. This idea can be applied to solving the RCF problem in such a way that total RCF is reduced.

In this paper, the optimization technique (a multiobjective artificial bee colony, (MOABC)) will try to obtain the optimal configuration for the distribution network, with the objective of minimizing RCF as well as power loss. This paper is organized as follows: in Section 2, the problem of reducing total RCF and total power loss is formulated. The implementation of the MOABC process is discussed in Section 3. A simple additive weighting approach has been utilized to combine both objective functions. In Section 4, the results are presented and discussed in detail.

2. Problem formulation

RCF in a distribution network cannot be avoided when the DG output is larger than the upfront feeder load, as shown in Figure 1. Reverse current helps reduce power losses in the distribution system, but it also affects the protection settings of the distribution system, including the fuse and circuit breaker. Thus, in this study, the network reconfiguration technique is used as an alternative method to reduce RCF in the distribution system.

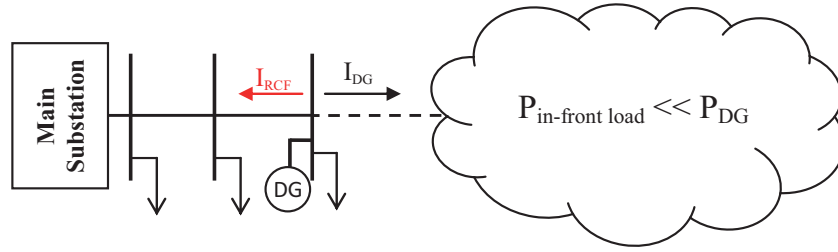


Figure 1. The reverse current flow phenomenon in a radial distribution network.

By using the optimization technique, the algorithm tries to determine the best new configuration of the system with minimum RCF and power loss. The total power loss in the system can be determined by using a standard power loss formula as shown in Eq. (1).

$$P_{losses} = \sum_{i=1}^L |I_i|^2 R_i, \quad (1)$$

where

I_i = current flow in the i th line.

R_i = resistance of the i th line.

L = total number of lines.

For the total RCF, the direction of the reverse current is monitored during load flow analysis. By assuming that the direction of initial current in the system (without DG) is positive, the changes in current direction (from the receiving bus to the sending bus) are recorded and the summation for the reverse current due to DG optimal output is done using Eq. (2).

$$RCF_{total} = - \sum_{i=1}^h I_i = - \sum_{i=1}^h \left(\frac{V_j \angle \delta_j - V_k \angle \delta_k}{r_{jk} + jx_{jk}} \right), \quad (2)$$

where

h = number of DG units causing RCF

j = sending bus

k = receiving end bus

r_{jk} = resistive value from j to k buses

x_{jk} = reactance value from j to k buses

δ = receiving bus voltage angle

The negative sign in the RCF_{total} equation is due to the reverse current that occurs in the network. Other constraints that need to be considered in network reconfiguration analysis are as follows:

a) Radial configuration:

The radial nature of the network should be maintained for every switch combination during the optimization process.

b) Isolation constraint:

All buses in the system need to be energized in order to make all loads in the network receive the generated power. In other words, there are no load disconnections during the reconfiguration process.

Therefore, all the constraints and objective functions that are described in this section are used during the optimization process. The MOABC algorithm determines the optimum configuration of the network with minimum power losses and reduced reverse current.

3. Implementation of the MOABC

The artificial bee colony (ABC) was introduced by [17] to solve the optimization problem, based on analyzing the behavior of bees searching for food. In ABC, 3 groups of bees (employer bees, onlooker bees, and scout bees) are constructed to find food positions. Each group of bees has their own responsibility in the process of finding the best solution. The initial scout bees are set out randomly in the search space for finding the initial nectar (solution), and the information obtained by the initial scout bee is passed down to the employer bees. Then the employer bees look for neighboring food (location) based on the initial bees' information, using Eq. (3). The information obtained by the employer bees is passed on to the onlooker bees. However, whether the onlooker bee goes to the next neighboring location depends on the amount of nectar available (the strength of solution – “probability”) given in Eq. (4). Therefore, it is possible that some food source locations might not be visited by any onlooker bee due to the small amount of nectar. When the food in the search area has been depleted, the onlooker bees will now become the scout bees again and look for the new food sources in random locations. The whole process will be repeated until the maximum iteration value set by the user is reached.

$$x_{ij}^{new} = x_{ij}^{old} + range \left(x_{ij}^{old} - x_{kj} \right) \quad (3)$$

$$P(f(x_i)) = \frac{Fitness(f(x_i))}{\sum_{i=1}^n Fitness(f(x_i))}, \quad (4)$$

where

x = optimized parameter than needs to be found (bees)

x_{ij} = value of i th bees at random j th dimension

x_{kj} = k th bees that are selected randomly from j th dimension

$f(x_i)$ = solution value for i th bee

Fitness = strength of the solution

In the present case of network reconfiguration analysis, the “bees” in the algorithm represent the opened switch condition in the distribution network. The two objective functions in the analysis are total power loss and total RCF. A simple additive weighting approach is adopted in the original ABC to create the MOABC. Furthermore, since the fitness unit between both objective functions is different (power loss in kW and RCF in A), the normalization process, using Eq. (5), is needed to add both objective functions’ results, as shown in Eq. (6). From Eqs. (5) and (6), the “bee” that has the minimum value in each objective function will give the lowest new objective function ($f(x)_i^{new}$) compared to the other bees in the population and indirectly give the higher fitness value (*Fitness* $f(x)$) as shown in Eq. (7).

$$Norm f(x_i) = \frac{f(x_i)}{f(x_i)_{min-iter}} \quad (5)$$

$$f(x_i)^{new} = \sum_{b=1}^{MaxObj} w_b(Norm f_b(x_i)) \quad (6)$$

$$Fitness f(x_i)^{new} = \frac{1}{1 + f(x_i)^{new}}, \quad (7)$$

where

$f(x_i)$ = solution value for i th bee

$f(x_i)_{min-iter}$ = minimum value achieved by N bees in current iteration

w = weight parameter for each objective function

b = number of objective functions (in this analysis, “*MaxObj*” = 2)

Figure 2 shows the pseudocode for implementing the MOABC in the reconfiguration process. In this analysis, the number of bees (N) is set to 40, the maximum iteration (max iter) is 300, and the limit to activate the scout bee (limit) is set to 100.

4. Results and discussion

MOABC’s performance in optimizing network reconfiguration is tested on a standard 33-bus radial distribution test system (Figure 3) under two different scenarios.

Scenario 1: 33-Bus distribution system with 100% loading

Scenario 2: 33-Bus distribution system without any DG

Three DG units based on minimization of losses are also located on bus 6, bus 16, and bus 25 to generate the reverse current in the distribution line. The discussions in the next subsection will focus on analyzing power loss and reverse current based on the following cases:

Case 1: Distribution system without any DG

Case 2: Distribution system with optimal DG output via ABC

Case 3: Distribution system with optimal DG output & reconfiguration via MOABC

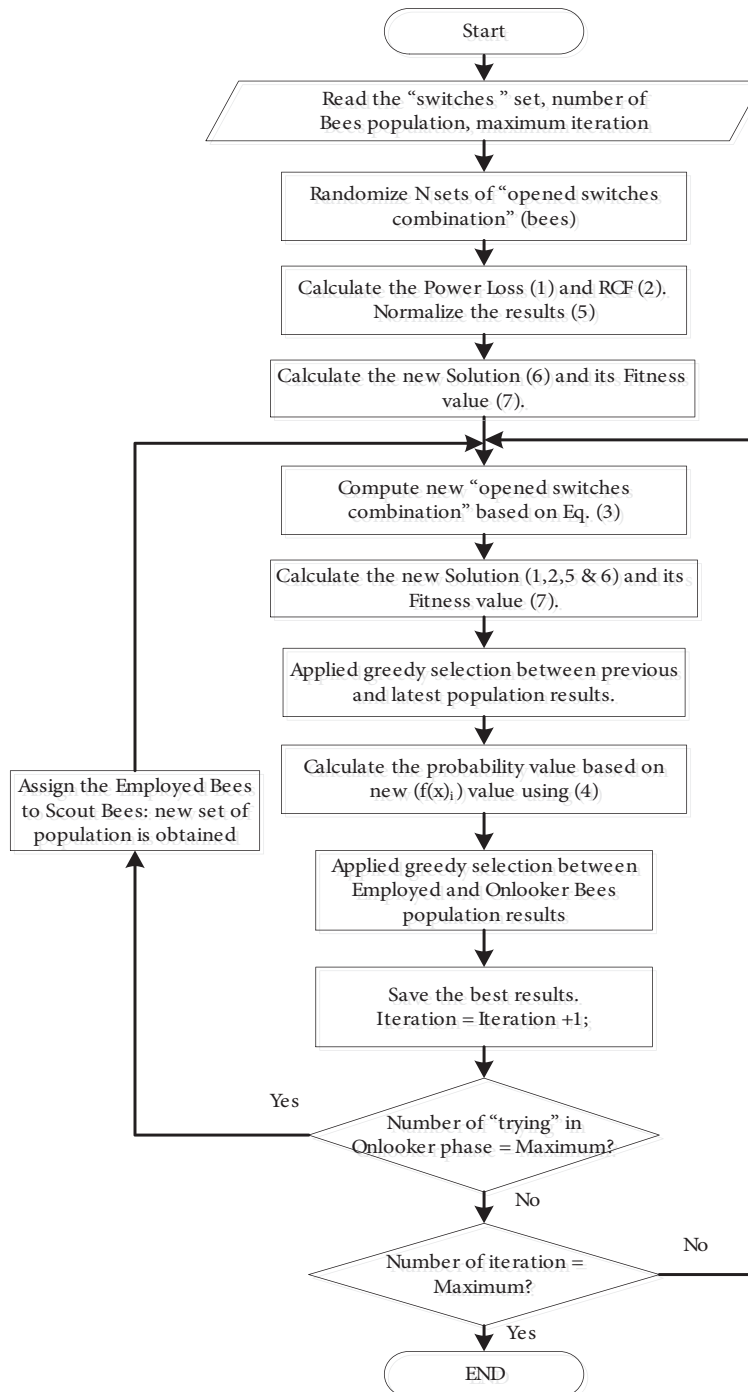


Figure 2. Pseudocode for MOABC.

4.1. Scenario 1: Standard 33-bus radial distribution system

Table 1 shows the power loss and RCF value for cases 1 and 2. The power loss in the network is reduced from 203.1854 kW to 33.2618 kW, which is an 83.63% decrease from the original power loss value when the connected DG operates optimally. However, the reverse current caused by DG in the system becomes 75.93 A, which is

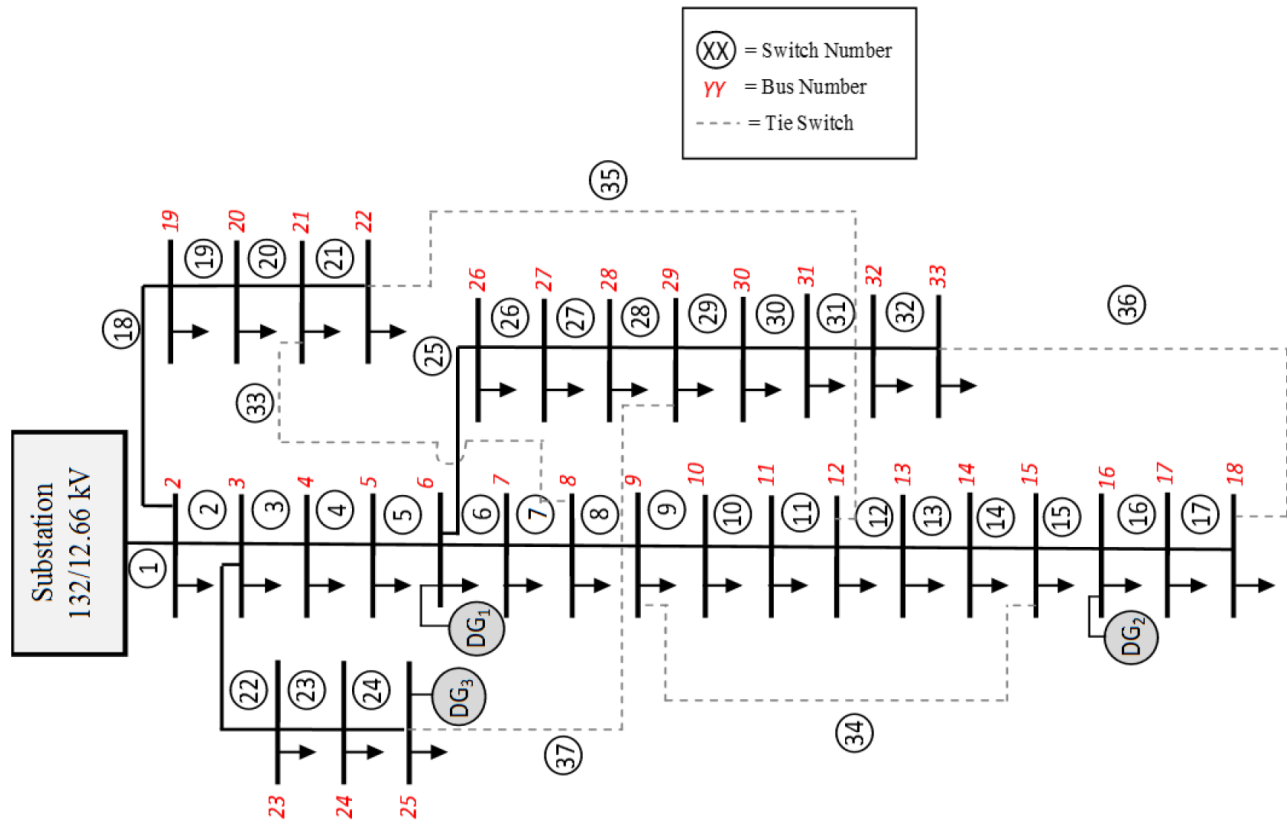


Figure 3. 33-Bus distribution system with 3 DG units.

very large. Thus, in order to reduce RCF, the reconfiguration process is applied to minimize the power loss and RCF using MOABC.

Table 1. The comparison of power loss and RCF with optimal DG output.

DG size _(location)	Tie switches position	Power loss (kW)	Total reverse current (A)
Without DG	33, 34, 35, 36, 37	203.1854	0.00
With three DG units DG ₆ = 1.7076 MW DG ₁₆ = 0.5470 MW DG ₂₅ = 0.7695 MW	33, 34, 35, 36, 37	33.2618	75.93

In the next step, case study 3 is carried out with 5 different weightage values (w_1 and w_2) for power loss and RCF, respectively, and the results are shown in Table 2.

From Table 2, the following points can be concluded:

1. The weightage of power loss minimization has been configured to maximum ($w_1 = 1$) and RCF to zero ($w_2 = 0$) in combination 1. As a result, the power losses have been reduced to the lowest value. Furthermore, RCF has also been reduced by 21.43% compared to the results in case 2 (distribution system with optimal DG output).

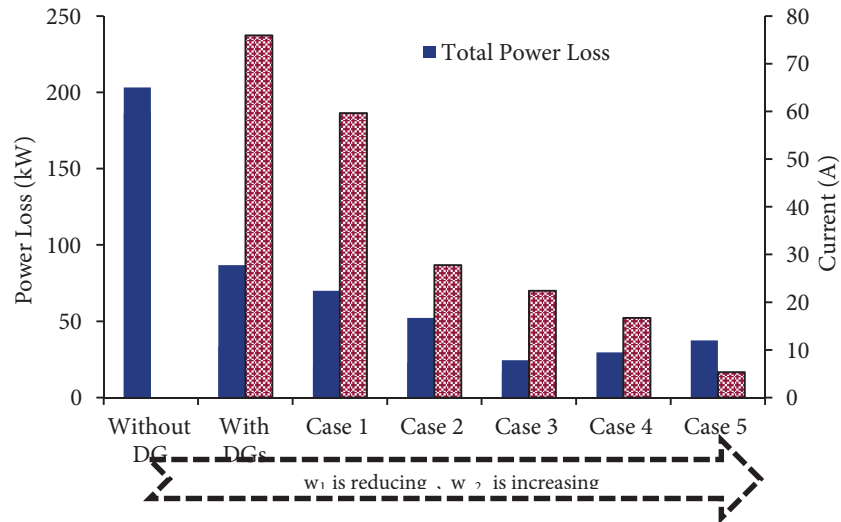
Table 2. Optimal configuration based on weight values.*
—vs3mm

Combinations	Weightage**		Opened switches	Power loss (kW)	Total reverse current (A)
	w_1	w_2			
1	1.0	0.0	20, 24, 32, 34, 35	20.5260	59.66
2	0.7	0.3	13, 15, 20, 24, 35	22.9677	27.76
3	0.5	0.5	11, 12, 15, 19, 24	24.5337	22.38
4	0.3	0.7	3, 13, 15, 24, 35	29.5457	16.69
5	0.0	1.0	4, 15, 24, 34, 35	37.4126	5.30

*Three DGs are also presented in the system at bus numbers 6, 16, and 25 ($DG_1 = 1.7076$, $DG_2 = 0.5470$, $DG_3 = 0.7695$).

** w_1 and w_2 are weighted functions to control the objective function. Here w_1 represents the loss function weightage and w_2 represents reverse current.

- By increasing the weightage of w_2 (combinations 2–5), the value of RCF is further decreased (Figure 4). However, the power loss has opposite results, where it has slowly increased.

**Figure 4.** The power loss and reverse current results after obtaining optimal configuration.

- In order to get an inside view of the total RCF, the contribution of different DG units in total RCF for different combinations is determined. The results are tabulated in Table 3. The results show that before the network reconfiguration, all three DGs caused RCF, and the largest RCF occurred in the line between buses 24 and 25. However, after the network reconfiguration implementation (combination 1), only 2 DGs units contribute to RCF. However, when the weight of RCF in MOABC is increased, only a single DG unit at bus 6 causes RCF (combinations 2–5).

In conclusion, the network will have very high RCF in certain branches if the optimization is only focused on minimizing power loss, and vice versa. Thus, with the use of a suitable weight in MOABC, the algorithm will determine a new configuration that is able to give low RCF as well as a smaller power loss increment.

Scenario 2: Standard 33-bus distribution system with 50% load

In order to validate the performance of the proposed network reconfiguration algorithm, a higher reverse current is formed in the system by increasing the loading factor (λ) to 50% on all buses in a standard 33-bus

Table 3. DG contribution in reverse current value and reconfiguration action.

Cases		Sending bus	Receiving bus	RCF (A)
With Optimal DG (w/o network reconfiguration)		5	6	15.18
		15	16	30.05
		24	25	30.71
		Total		75.93
With optimal DG placements and network reconfiguration	Combination 1	5	6	27.98
		15	16	31.68
		Total		59.66
	Combination 2	5	6	27.76
		Total		27.76
	Combination 3	5	6	22.38
		Total		22.38
	Combination 4	5	6	16.69
		Total		16.69
	Combination 5	5	6	5.30
		Total		5.30

network, as shown in Eqs. (8a) and (8b).

$$P_{L1} = (1 + \lambda) P_{L0} = \lambda P_{L0} \quad (8)$$

$$Q_{L1} = (1 + \lambda) Q_{L0} = \lambda Q_{L0},$$

where

P_{L0} and Q_{L0} = the initial active and reactive load on all buses, respectively.

P_{L1} and Q_{L1} = the modified active and reactive load on all buses, respectively.

λ = loadability factor. In the present case, λ is equal to 50.

By using an ABC algorithm, optimal DG placement and outputs were found at bus 6, bus 15, and bus 25 with 2.5854 MW, 0.8215 MW, and 1.1545 MW, respectively, for DG₁, DG₂, and DG₃. The results are tabulated in Table 4.

Table 4. The optimal opened switch results for modified 33-bus distribution network.

DG size _(location)	Opened switch	Power loss (kW)	Total reverse current (A)
Without DG	33, 34, 35, 36, 37	498.5787	0.00
With three DG units DG ₆ = 2.5854 DG ₁₆ = 0.8215 DG ₂₅ = 1.1545	33, 34, 35, 36, 37	76.7730	114.06

The data in Table 4 show that the total power loss in the system decreased from 498.5787 kW to 76.7730 kW. However, 114.06 A of RCF existed in the system due to these optimal DGs' output. Therefore, in order to reduce RCF, the MOABC algorithm is applied where the corresponding weightage of total power loss and total RCF varies (w_1 and w_2). Table 5 shows the performance of network reconfiguration action and the following points can be concluded:

1. By opening the optimum switch combinations 20, 24, 32, 34, and 35 and closing the other switches, RCF and power loss in the system were reduced by 21% and 39% respectively (combination 1).

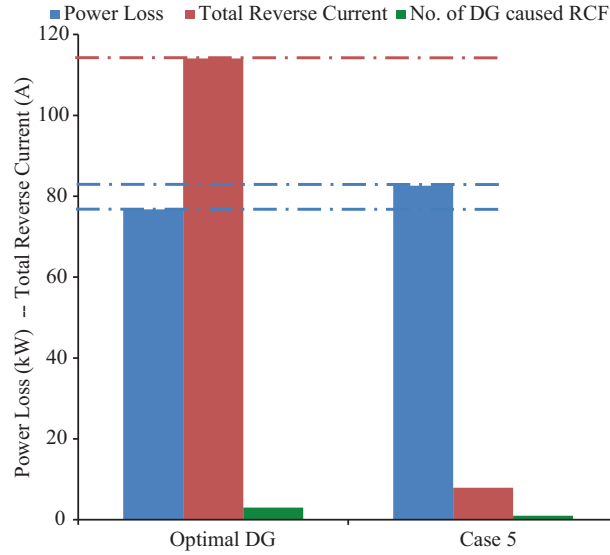
Table 5. Optimal configuration based on weight values.*

Cases	Weightage**		Opened switches	Power loss (kW)	Total RCF (A)
	w_1	w_2			
Combination 1	1.0	0.0	20, 24, 32, 34, 35	46.8904	90.80
Combination 2	0.7	0.3	13, 15, 20, 24, 35	52.3316	42.61
Combination 3	0.5	0.5	10, 12, 15, 20, 24	53.3925	42.52
Combination 4	0.3	0.7	3, 11, 13, 15, 24	70.8798	25.06
Combination 5	0.0	1.0	4, 12, 15, 24, 35	82.6204	7.95

*Three DGs are also presented in the system at bus numbers 6, 16, and 25 ($DG_1 = 1.7076$, $DG_2 = 0.5470$, $DG_3 = 0.7695$)

** w_1 and w_2 are weighting coefficients to control the objective function. w_1 represents the loss function weightage while w_2 represents reverse current.

2. Similar to previous discussions, increasing w_2 values in the MOABC reduces total RCF in the system and causes a small increase in total power losses.
3. Comparing the results for combinations 1 and 5, the small increase in power loss (7.61%) is acceptable compared to the 93% reduction in RCF (Figure 5). Furthermore, it is clear that the number of RCF-causing DGs is also reduced from 3 units to just 1 unit in combination 5.

**Figure 5.** The comparison between optimal DG and reconfiguration (case 5) results.

From the discussion, it has been proven that when considering RCF in finding optimal reconfiguration, the impact of protection malfunction in the distribution network can be reduced. Furthermore, the increment of load in the system indirectly causes the reverse current to become worse. Thus, the reconfiguration process can be done regularly with the load increment without any additional cost required.

5. Conclusion

RCF caused by DG placement in the distribution network may affect the setting of existing fuse and other protection devices. Therefore, in this paper, a strategy based on network reconfiguration has been adopted to

solve the RCF problem in the presence of DGs. A MOABC algorithm is used to balance the impact of RCF as well as power loss. The proposed method is tested on standard and modified 33-bus radial distribution networks. From the results, the following points can be concluded.

1. Using a simple additive weightage approach, total RCF can be reduced by up to 80%–90%; however, the total active power loss will increase. According to the results, the total active power loss at optimum solution is still 80% less than without DG.
2. The network reconfiguration process not only reduces the total RCF in the network, but also reduces the number of DG units that contribute in the RCF phenomenon.

From these results, it can be concluded that implementing MOABC in the reconfiguration process, with power loss and RCF as the objective functions, tremendously improved power system performance, especially in terms of RCF and power loss reductions.

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